WATER DISTRIBUTION SYSTEM INFRASTRUCTURE ANALYSIS

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The Problem

One of the most vital services to mankind is an adequate water supply system, without which our society cannot survive. Industrial growth can be hampered by the lack of adequate water supply systems. The lack of adequate water supply systems is due to both the deterioration of aging water supply systems in older urbanized areas, and to the nonexistence of adequate water supply systems in many areas. Methods for evaluation of the nation's water supply services need to consider not only rehabilitation of existing urban water supply systems but also the future development of new water supply systems to serve expanding population centers and underdeveloped communities such as along the U.S.-Mexican border. Both the adaptation of existing technologies and the development of new innovative technologies will be required to improve the efficiency and cost effectiveness of future and existing water supply systems and facilities.

An EPA survey (Clark et al., 1982) concluded that the distribution facilities in water supply systems account for the largest cost item in future maintenance budgets. The aging, deteriorating distribution systems in many areas raise tremendous maintenance decision-making problems which are further complicated by the expansion of existing systems. Deterioration of the water distribution systems in many areas has translated into a high proportion of unaccounted-for water due to leakages, which not only is a loss of a valuable resource, but also raises concerns of safe drinking water caused by possible contamination through cracked pipes. As an example, the following percentages of water lost through leakage have been reported in the literature: 17% in Boston, 15% in St. Louis, 15% in Cleveland, 14% in Pittsburgh, and 14% in Tulsa. Many have estimated the capital needs to rehabilitate urban water distribution systems in the U.S. to range from $75 to $110 billion (1972 dollars) over the next twenty years (Choate and Walter, 1981). Traditionally, the investments in infrastructure maintenance have been small and given minor attention.

The reliability of the existing aging systems is continually decreasing. Only recently have municipalities been willing or able to finance rehabilitation of deteriorating pipelines, and are still deferring needed maintenance and replacement of system components until a catastrophe or the magnitude of leakage justifies the expense of repair. Water main failures have been extensive in many cities. As an example, in 1973 in Houston, Texas, there were 5,149 breaks in the 3,998 miles of water mains.

The design or extension of a water distribution system generally involves large capital outlays as well as the continuing operation, maintenance, and repair costs. Because of the complexity of the problem arising from the large number of design components and their interaction, automated procedures that result in reliable, but minimal, cost designs are desired. Conventional design approaches consist of selecting a network configuration, pipe sizes, reservoir sizes and elevations, and pumping facilities. This process is usually a trial and error procedure that attempts to find a design representing a low-cost solution. No guarantee can be made that the resulting distribution system is a minimum cost solution, nor is any measure generally made of the reliability of the designed system.

A survey of methods used by municipal water utilities was performed (Mays et al., 1989). This survey had three basic purposes: (1) to obtain failure data for water distribution system components; (2) to examine the methods used by utilities

to collect and maintain data on the maintenance, failure and repair of various components of water distribution systems; and (3) to identify existing sources of computerized data bases that have been developed and maintained. As a result of this survey and discussions with many municipalities, it was concluded that:

> Cities do not have in existence data base systems that store water utility networks, or information on maintenance, failure, or repair. Of the utilities that responded, only two have any kind of system that could be used effectively. No computerized data was available on water supply system components other than water mains.

Where is our Technology?

A review of the literature by Mays et al. (1989) revealed that there is currently no universally acceptable definition or measure of the reliability of water distribution systems. Reliability can be defined as the probability that a system performs its mission within specified limits for a given period of time in a specified environment. For a large system, with many inter-active subsystems (such as a water distribution system), it is extremely difficult to analytically compute the mathematical reliability. Accurate calculation of a mathematical reliability requires knowledge of the precise reliability of the basic subsystems or components and the impact on mission accomplishment caused by the set of all possible subsystem (component) failures.

The so-called optimal or minimum cost design of water distribution systems has been approached from many different directions, including the use of several types of optimization techniques. Most of the approaches place emphasis on designing the water distribution system to function under normal loading conditions using peak hourly demands, maximum daily demands, etc. Very little work has been done on abnormal or emergency loading conditions such as fire demands, pump failure, control valve failure, power outages, and broken links. Investigators have explicitly incorporated measures of reliability into optimization models to predict system operation under emergency loading conditions. New methods have been reported in the literature recently for "optimization-reliability" based evaluation and design of water distribution components and systems.

An American Society of Civil Engineers (1989) task committee on Risk and Reliability Analysis of Water Distribution Systems took a serious look at the modernization of the design and analysis of water supply systems, in particular the reliability-based design and analysis of new and aging water distribution systems. Through this committee effort, ideas and concepts were identified and developed to modernize the process of designing and analyzing water distribution systems. The final report discusses in great detail many new concepts of optimization and risk and reliability analysis and how they can be applied to water distribution systems that should prove to be useful in our future analysis and design of these systems.

In summary there is a definite need for municipalities and engineers to have new methods to analyze and design the water distribution infrastructure. Many new methods have been developed by researchers at universities; however there has been very little effort in the transfer of technology to get these models into a form that can be used directly and easily by municipalities and practicing engineers.

References

American Society of Civil Engineers. 1989. Reliability Analysis of Water Distribution Systems. Edited by Larry W. Mays, New York, N.Y.

Choate, P. and S. Walter. 1981. "America in Ruins." Washington, D.C.: The Council of State Planning Agencies.

Clark, R.M., C.L. Stafford and J.A. Goodrich. 1982. "Water Distribution Systems: A Spatial and Cost Evaluation." *Journal of the Water Resources Planning and Management Division.* ASCE Vol. 108, No. WR3. October: 243-256.

Mays, L.W., K.E. Lansey, N. Duan, M.J. Cullinane, L. Brion, and Y. Bao. 1989. "New Methodologies for the Design and Analysis of Water Distribution Systems." CRWR Report # 227 (July). Austin, Texas: Center for Research in Water Resources, The University of Texas.